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Characteristics of Meso- β -Scale Deep Convection Over the Eastern Tropical Atlantic

Lee R. Hoxit

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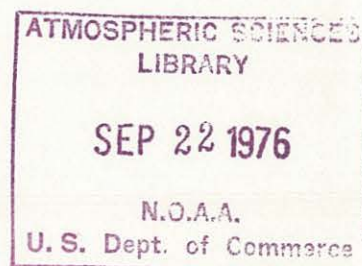


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Chemistry Laboratory

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Elliot Richardson, Secretary

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Lee R. Hoxit

SMS/GOES infrared imagery is used to estimate the temporal and spatial variability of isolated mesoscale convective systems over the tropical Eastern Atlantic for a study period (July 17–Sept. 6, 1974) that includes most of the GATE experimental period. The region along 10°N experiences the greatest frequency of these storms. A pronounced diurnal variation is found in the times of initial development with maximum frequencies near midnight. Typical life cycles encompass roughly 5–10 hours. The data suggest a tendency for these systems to develop in regions of low-level convergence and mid-tropospheric divergence.

1. Introduction

In recent years, several studies have been devoted to defining the frequency and characteristics of cloud systems over the tropical oceans. See, for example, Williams and Gray (1973) and Yanai et al. (1973). The 1974 GARP Atlantic Tropical Experiment (GATE) also focused on tropical cloud systems with particular emphasis on “cloud clusters”. The tropical cloud cluster is an ensemble of convective clouds with characteristic dimensions of 3–6° latitude by 3–6° longitude.

The first Synchronous Meteorological Satellite (SMS) of the Geostationary Operational Environmental Satellite (GOES) series was positioned over the Equator near 45°W during GATE. Both visible and infrared imagery were available and, for the first time, the evolution of

the individual convective clouds and meso- β cloud systems could be monitored over the entire tropical Atlantic on an almost continuous basis. Casual examination of the satellite photos showed the frequent occurrence of strong convective systems with characteristic dimensions of 1–2° latitude, considerably smaller than the typical cloud cluster. Weickmann (1975) reported on the evolution of these systems and likened the rapid development of cold cloud, as seen on sequential satellite photos, to the development of supernova stars—hence the name “supernova storms”. He also noted an apparent tendency toward development during the night. One of the purposes of this study is to determine in more detail the nature of that apparent diurnal variation. In addition, we seek a better description of the basic characteristics and spatial variation of these cloud systems.

2. Procedure

Storms were selected by viewing 4×4 nautical mile resolution infrared imagery from the SMS/GOES. Photos were typically available at 30-minute intervals, although the time intervals ranged upwards to 2 hours in a few instances. Cloud systems selected for study met the following criteria:

- (1) Rapid growth of cold cloud in region where little or no cold cloud had existed. Typical growth period was 2–5 hours.
- (2) Bright mushroom or oval appearance in the growing stage. This is a signature for developing cumulonimbus clouds.
- (3) Mature stage with horizontal dimensions of $\frac{1}{2}$ – 2° latitude, which corresponds roughly to the meso- β scale as recently defined by Orlanski (1975).

The study was confined to the period from July 17 to Sept. 6, 1974. It included only the area between the Equator and 20°N , and between 20° and 40°W .

3. Results

3.1 Spatial Distribution

Ninety-two systems were selected during the 52-day period. Table 1 lists their dates, times, and locations; figure 1 shows their spatial distribution. Actually, these are the positions during the early stages of development. Since the typical lifetime is only a few hours, the horizontal displacements are not very large. Most of the storms formed near 10°N with a slight south-southwest–east-northeast orientation of the axis of maximum frequency.

3.2 Diurnal Variations

The diurnal variation in initial development of the cloud systems is shown in figure 2. Maximum frequencies are indicated near 0100 GMT or 2300 LT (local time) with a weak secondary peak near 1600–1700 LT. A broad minimum is shown for the period from 0500 to 1400 LT and a second minimum is found near 2000 LT. The frequencies

near midnight are roughly four times greater than those observed near local noon.

The major features of figure 2 are similar to those presented by Martin (1975). Martin's results, also based on satellite imagery, are shown in figure 3 and are applicable to the initial development of clusters $\geq 1 \text{ deg}^2$ over the eastern Atlantic during the three phases of GATE. Of the 92 cloud systems included in figures 1 and 2, approximately one-third grew beyond the 2° latitude diameter criterion or merged with other cloud systems to form typical cloud clusters. Many of the storms treated here were also included in Martin's study although the area of study and the period of record are somewhat different.

The results shown in figure 2 complement the rapidly increasing evidence that tropical oceans experience a significant diurnal oscillation in the amount of convective clouds and rainfall. Holle (1968) computed the diurnal variation of the number of echoes in an area surrounding the research vessel *Crawford* located at 13°N , 55°W during the period August 12–September 3, 1963. The frequency of echoes during the night was double the frequency for the daytime hours. The period from 0100 to 0500 LT had roughly three times as many echoes as the period from 0900 to 1300 LT.

Jacobson (1975), in the most extensive analysis to date of the diurnal variability of rainfall and convection over the tropical oceans, shows considerable evidence of a rainfall maximum near 0500–0600 LT and a minimum near 2000 LT. Remember that the parameter plotted in figure 2 is the time of initial development of the meso- β cloud systems. With a typical 2- to 5-hour growth period, we would expect the times of maximum rainfall produced by these systems to lag behind the times of initial development by a similar period. Thus there is reasonable agreement between the results presented here and those presented by Jacobson and by Holle, even though the meso- β systems produce only a portion of the total rainfall.

Marks (1975), in a preliminary study of radar data taken aboard the research vessel *Quadra* (9.1°N , 22.2°W approximate location), did not find any strong evidence of a late-night–early-morning maximum in rainfall. In fact, he found predominance of echoes in the late afternoon. The reasons for the differences in Marks's result as compared with those presented in the previous paragraph are not clear. A partial explanation may be that the *Quadra's* position was close enough to the African coast to be in a transition zone, with many of the continental systems reaching this region before dissipating.

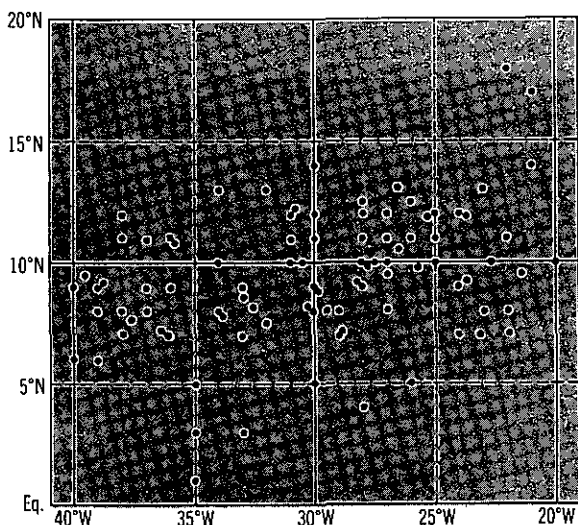


Figure 1. Locations of the 92 cloud systems during the early stages of development.

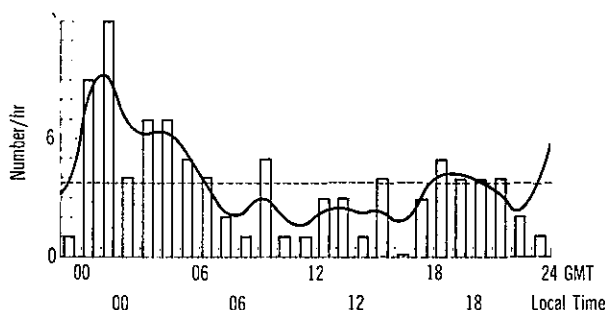


Figure 2. Diurnal variation in initial development of 92 storms. Both GMT and local time (LT) at 30°W are shown. The number within each hourly period is given by the height of the bars. The curve results from applying a $\frac{1}{4}$ - $\frac{1}{2}$ - $\frac{1}{4}$ smoothing scheme to the hourly totals; the horizontal dashed line represents the average for all hours.

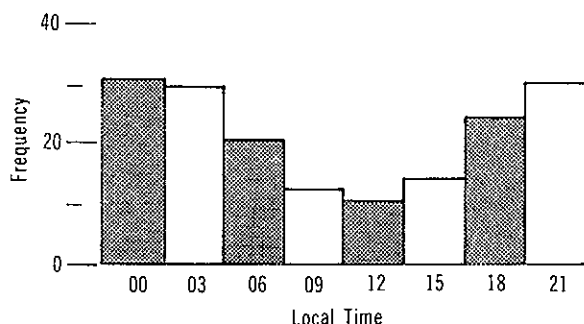


Figure 3. Diurnal variation in the time of appearance of cloud clusters ≥ 1 deg² for the Eastern Atlantic, during the three phases of GATE. Location: 10°E to 40°W and 10°S to 25°N in Phase 1; 0° to 25°N, 0° to 30°W thereafter, with all land and coastal water excluded. From Martin (1975).

3.3 Environmental Characteristics

An attempt was made to isolate the prevailing features of the environmental flow field near the time of storm development. Streamline analyses (GATE preliminary data, "A" series, charts) for the surface, 850-, 700-, and 500-mb levels were utilized. Analyses were available at 6-hour intervals for the duration of the GATE field effort.

The analyses used were those within the period from 4 hours prior to 2 hours after initial storm development. Flow characteristics for the region of storm development were examined subjectively and assigned a number according to the criteria given in table 2. In some cases a lack of data prohibited a complete streamline analysis of the study area. Consequently, only one-half to two-thirds of the 92 storms could be classified. Results of the classification are in table 3.

The tendency is toward convergence and cyclonic curvature in the surface streamlines, changing to a tendency toward divergence and anticyclonic flow at 500 mb. Intuitively, we expect this pattern with strong convective systems. However, because the streamline analyses were only preliminary, and because the classification scheme is only qualitative, table 3 can be used only as an indication of a general tendency.

4. Selected Examples

The following section presents time series satellite photos for three individual cases. The first two cases show the evolution of several cloud systems included in the 92-storm sample shown in figures 1 and 2. The third case presents a rather spectacular convective cloud development in an organized system with much cirrus cloud already in existence. Because it did not fit the selection criteria the third case was not included in the data sample.

4.1 August 10, 1974

Figure 4 presents the hourly infrared satellite images for the period 0300–2000 GMT Aug. 10, 1974. The rapid development of strong convective clouds started near 0500 GMT in the region of 25°W, 10°N, with three or four systems developing almost simultaneously. Another system appeared at 30°W, 14°N at 700 GMT. An hour later (0800 GMT) several new cells appeared in a linear orientation in the vicinity of 25°W, 12°N.

Table 1.
Dates, Times, and Locations of the Cloud Systems Studied

System Number	Date	Time (GMT)	Location
1	July 17-18	2230-0100	30°W-5°N
2	July 19	0900-1030	33°W-9°N
3	July 21	0900-1100	26°W-11°N
4	July 21	1800-2330	28°W-11°N
5	July 22	0300-0800	26.5°W-10.5°N
6	July 23	1930-2200	33°W-3°N
7	July 24	0100-0300	37°W-8°N
8	July 24	1200-1600	29°W-7°N
9	July 24	2200-2330	24°W-9°N
10	July 25	2100-2300	28°W-12°N
11	July 26	0900-1200	38°W-11°N
12	July 26	1500-1800	36°W-11°N
13	July 27	0000-0300	29°W-8°N
14	July 27	0000-0300	28°W-9°N
15	July 27	0100-0700	39.5°W-9.5°N
16	July 28	0000-0500	35°W-5°N
17	July 29	0500-0730	21°W-17°N
18	July 29	0500-0730	22°W-18°N
19	July 29-30	2330-0500	27°W-8°N
20	July 30	1730-2300	29°W-7°N
21	July 31	0300-0700	21.5°W-9.5°N
22	July 31	1530-1830	36°W-9°N
23	Aug. 1-2	2130-0300	38°W-7°N
24	Aug. 5	0400-0800	38°W-8°N
25	Aug. 5	1330-1800	34°W-8°N
26	Aug. 6	0300-0600	28°W-10°N
27	Aug. 7	0930-1230	30.5°W-10°N
28	Aug. 7	1830-2300	27°W-10°N
29	Aug. 8	0230-0830	28°W-10°N
30	Aug. 10	0430-0900	26°W-9.5°N
31	Aug. 10	0430-0900	23.5°W-9°N
32	Aug. 10	0500-0900	22.5°W-10°N
33	Aug. 10	0600-1000	23°W-7°N
34	Aug. 10	0700-1030	30°W-14°N
35	Aug. 10	0730-1200	25°W-12°N
36	Aug. 10	0900-1200	26.5°W-13°N
37	Aug. 10	1800-2200	34°W-13°N
38	Aug. 12	0000-0500	35°W-1°N
39	Aug. 12	0000-0500	35°W-3°N
40	Aug. 12	1400-1800	39°W-6°N
41	Aug. 14	0330-0900	23°W-13°N
42	Aug. 14	0500-0900	30°W-9°N
43	Aug. 14	1730-2330	31°W-12°N
44	Aug. 15	0100-0400	28°W-12.5°N
45	Aug. 15	0600-0900	26°W-12.5°N
46	Aug. 16	0000-0500	39°W-9°N
47	Aug. 16	0400-0900	20°W-10°N
48	Aug. 17	0000-0730	30°W-9°N

Table 1.
(continued)

System Number	Date	Time (GMT)	Location
49	Aug. 17	0100-0600	36°W- 7°N
50	Aug. 17	0300-0730	27.5°W-10°N
51	Aug. 18	0100-1000	29.5°W- 8°N
52	Aug. 18	0200-1000	28°W- 9°N
53	Aug. 18	0400-1100	37.5°W- 7.5°N
54	Aug. 18	0600-0900	32.5°W- 8°N
55	Aug. 18	1200-1800	25°W-10°N
56	Aug. 18	1300-1600	33°W- 8.5°N
57	Aug. 18	1500-2000	27°W-11°N
58	Aug. 18	2000-2300	30°W- 8°N
59	Aug. 18	2000-2300	36°W- 7°N
60	Aug. 19	0100-0700	30°W- 8°N
61	Aug. 19	0100-0700	34°W- 8°N
62	Aug. 19	0830-1100	22°W-11°N
63	Aug. 20	0400-0700	25°W-12°N
64	Aug. 20	0500-0900	31°W-10°N
65	Aug. 21	2100-2330	27°W-12°N
66	Aug. 28	0000-0600	27°W- 9.5°N
67	Aug. 28	1300-1800	38°W-12°N
68	Aug. 28	2130-2330	36°W-11°N
69	Aug. 29	0200-0800	40°W- 6°N
70	Aug. 29	2030-2230	40°W- 9°N
71	Aug. 30	0100-0600	32°W- 7.5°N
72	Aug. 30	0100-0600	21°W-14°N
73	Aug. 30	1930-2230	30°W-11°N
74	Aug. 30	1900-2300	24°W-12°N
75	Aug. 31	0600-0900	31°W-12°N
76	Aug. 31	1000-1600	28°W- 4°N
77	Aug. 31	1100-1500	30°W-12°N
78	Sept. 1	0100-0400	38°W- 8°N
79	Sept. 1	0300-0500	34°W-10°N
80	Sept. 1	0300-0630	26°W- 5°N
81	Sept. 1	1230-1500	32°W-13°N
82	Sept. 1	1500-1830	39°W- 9°N
83	Sept. 1	1800-2000	33°W- 7°N
84	Sept. 1	1830-2300	37°W-11°N
85	Sept. 2	0100-0600	24°W- 7°N
86	Sept. 2	0200-0600	25°W-11°N
87	Sept. 3	1900-2300	22°W- 7°N
88	Sept. 4	0000-0400	23°W- 8°N
89	Sept. 5	1700-2000	31°W-11°N
90	Sept. 6	0100-0600	24°W-12°N
91	Sept. 6	0430-0700	22°W- 8°N
92	Sept. 6	2000-2300	37°W- 9°N

Note: Time intervals indicate time of initial development to time of maximum intensity or to time the system merged with other cloud systems or grew beyond 2° latitude in diameter. Location coordinates indicate positions at beginning of development.

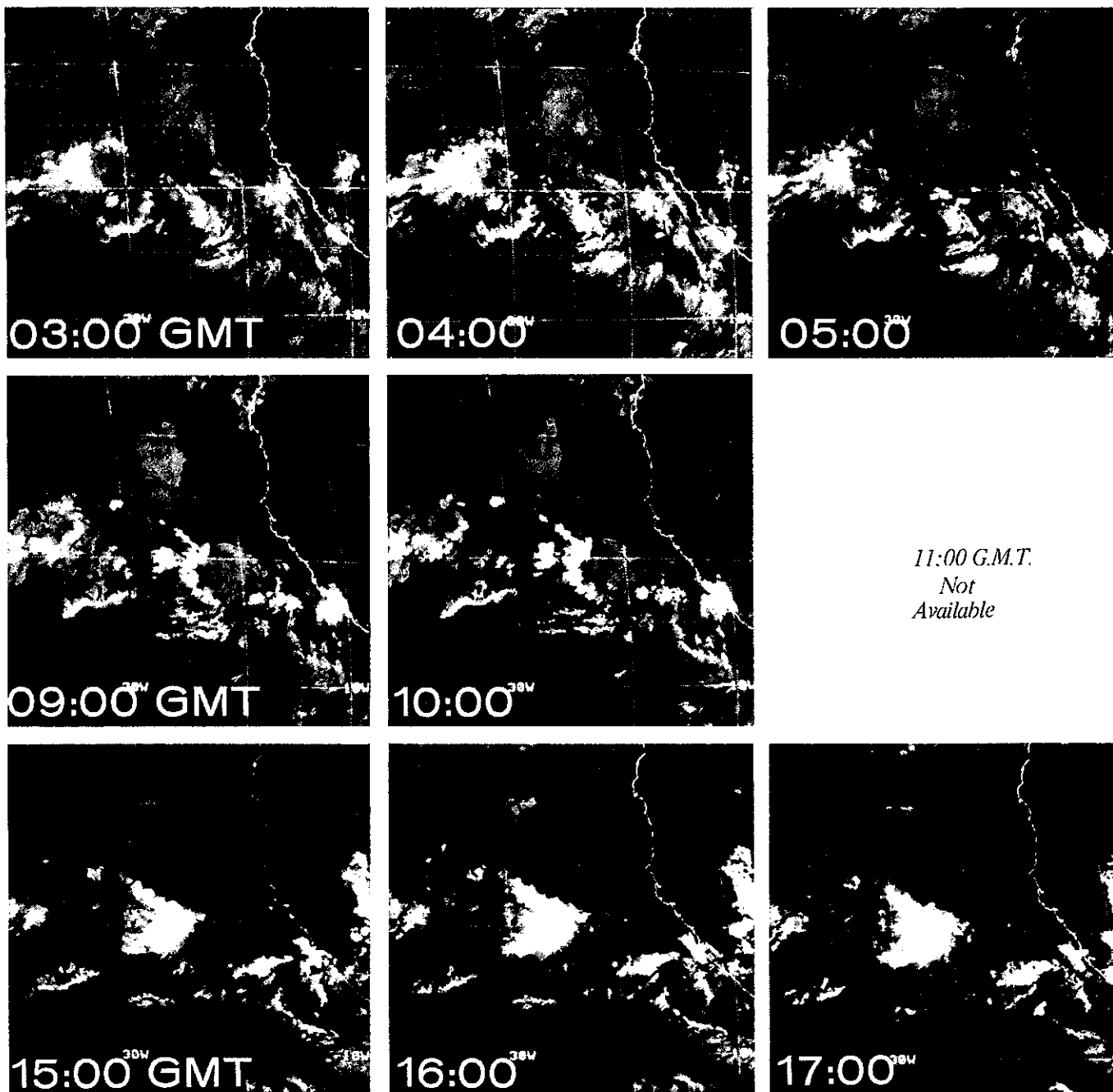
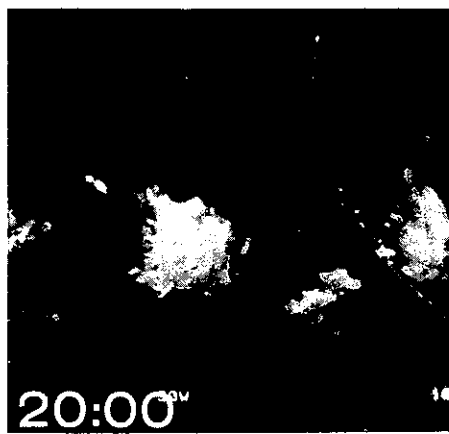
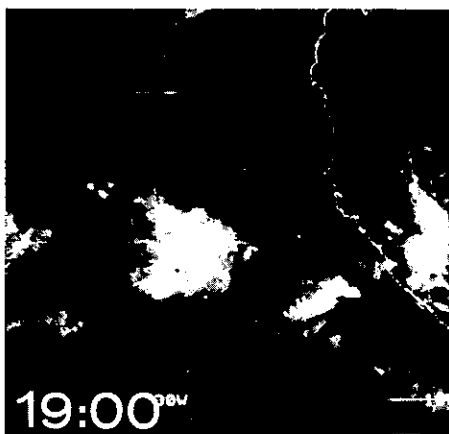
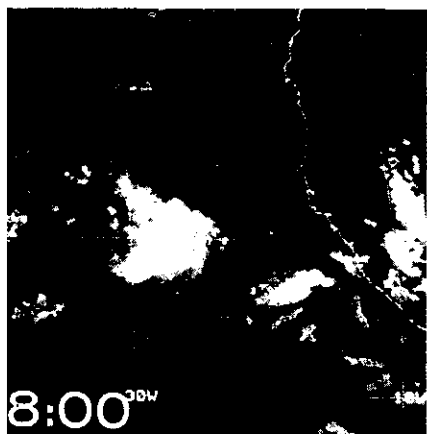
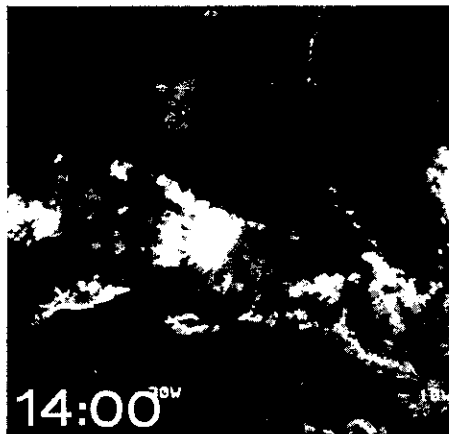
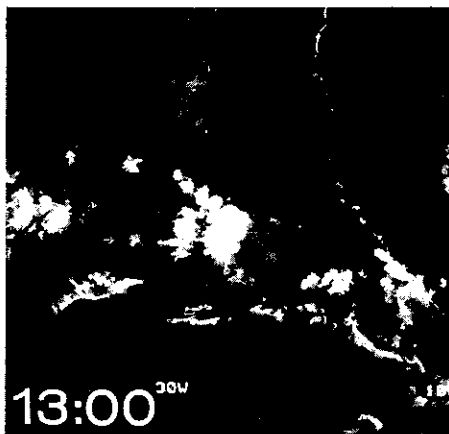
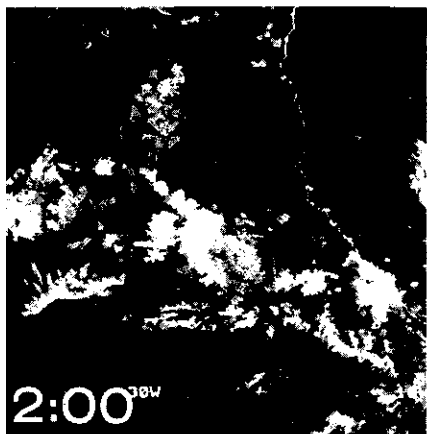
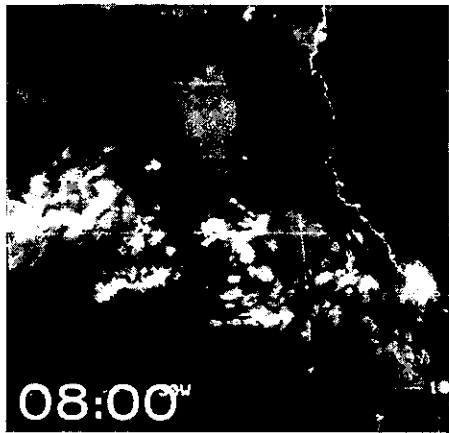
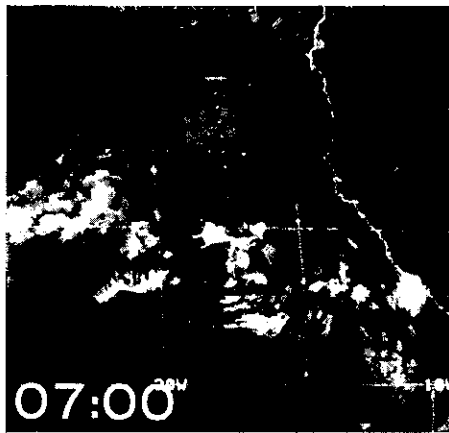


Figure 4. Hourly SMS/GOES imagery; 4x4 nmi resolution; August 10, 1974.



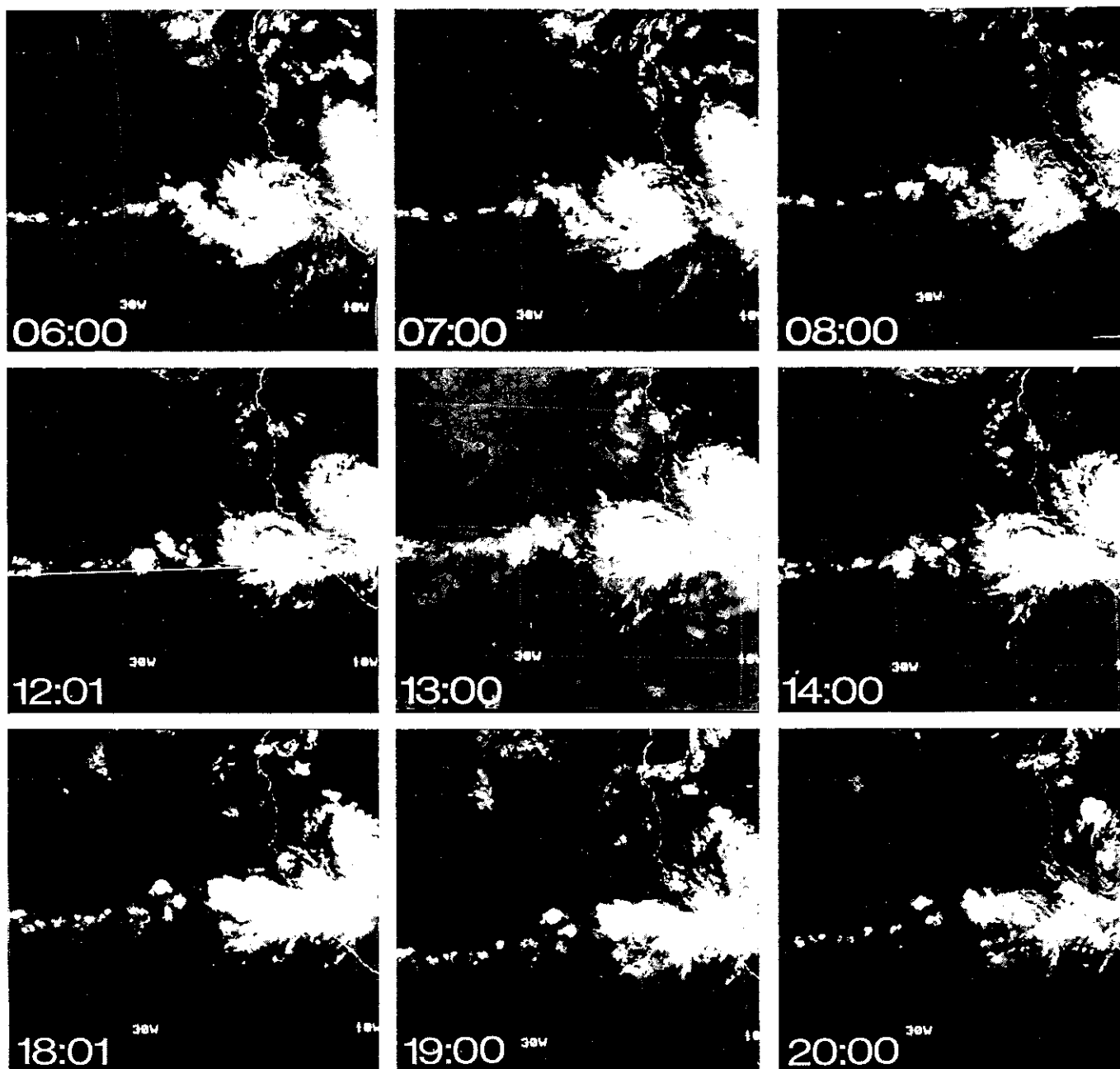
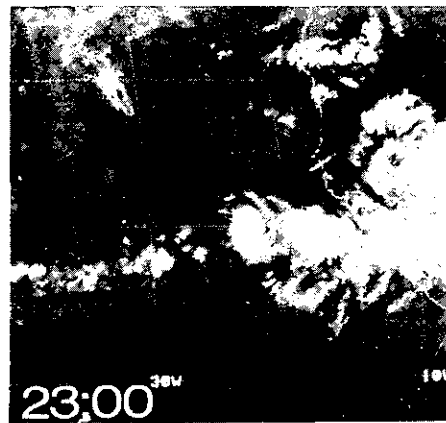
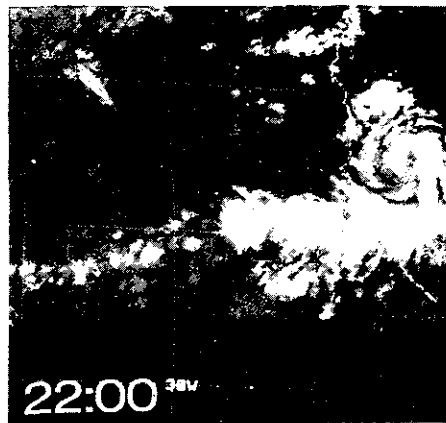
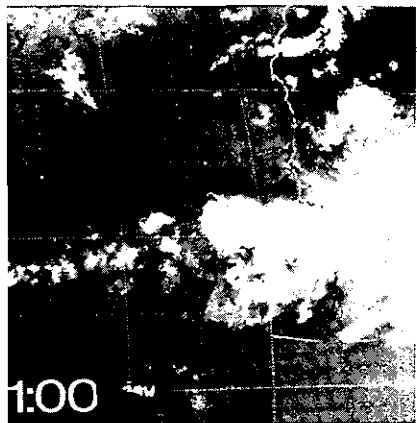
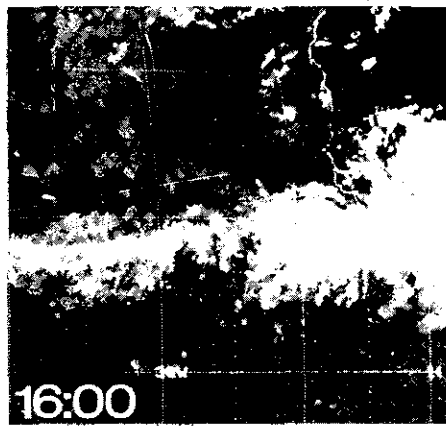
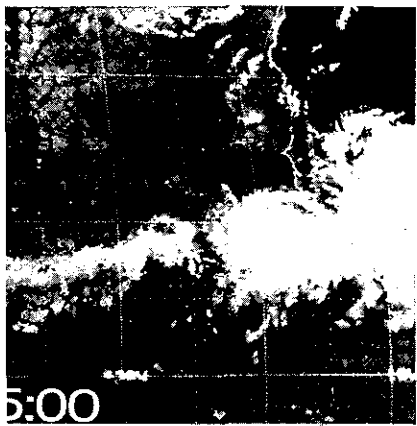
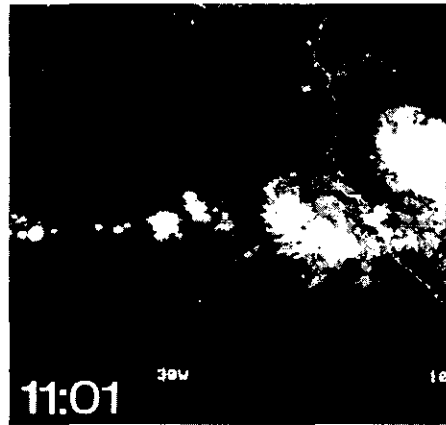
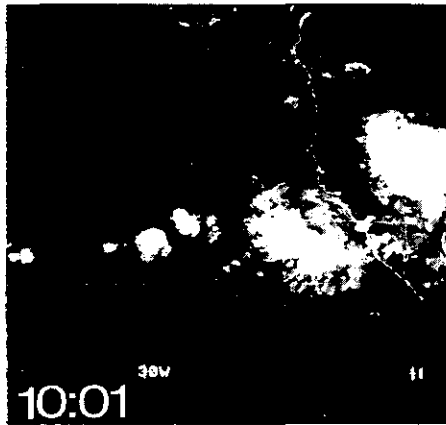
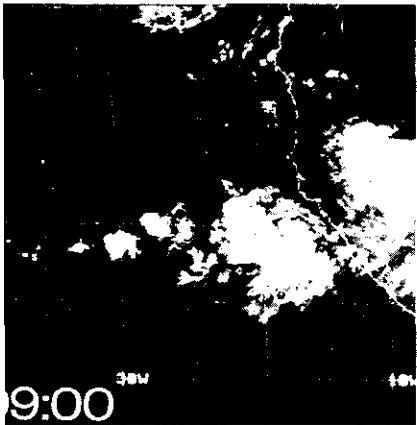


Figure 5. Hourly SMS/GOES imagery; 4x4 nmi resolution; August 18, 1974.



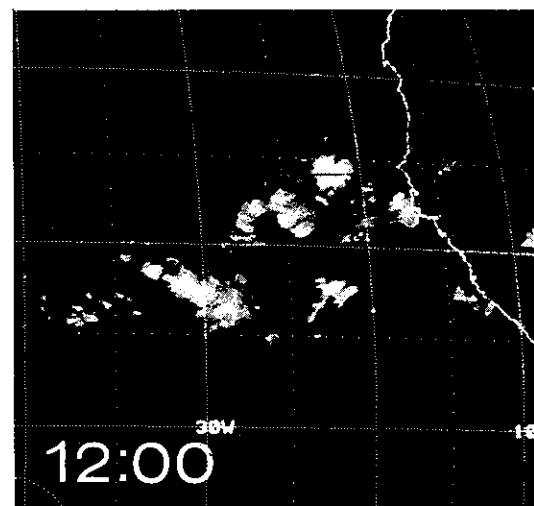
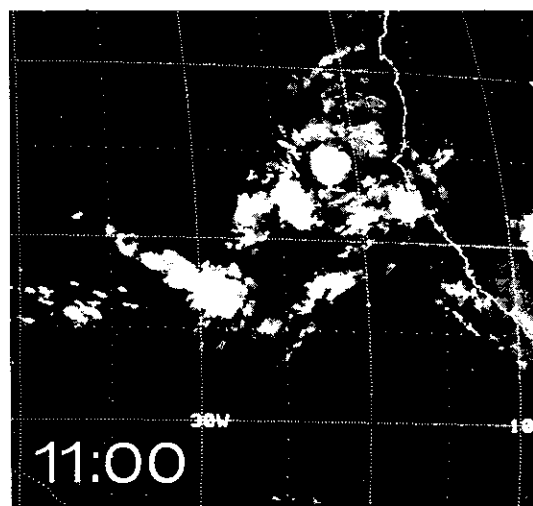
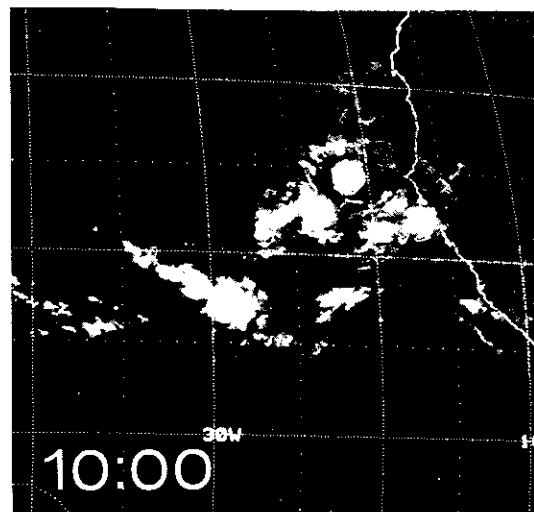
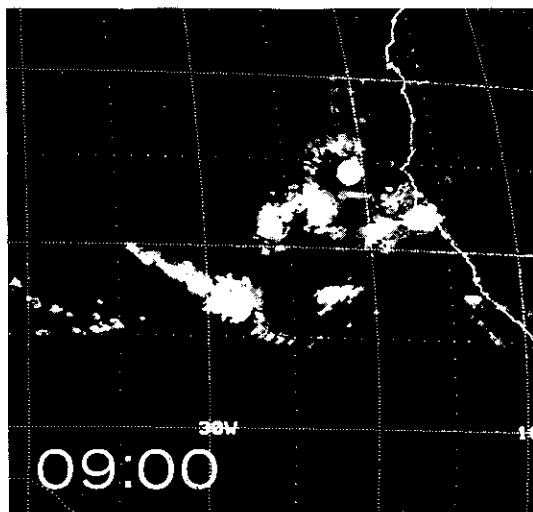
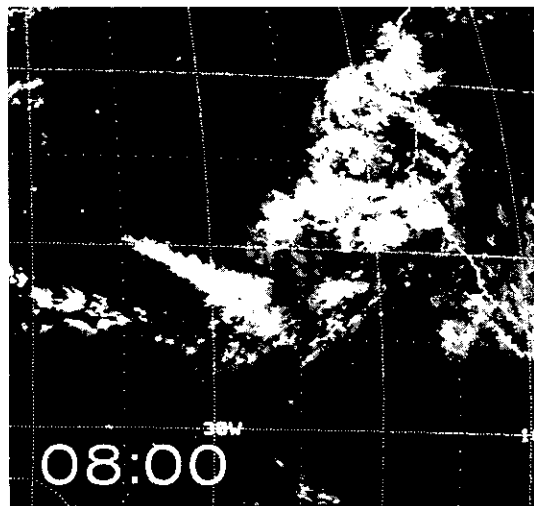
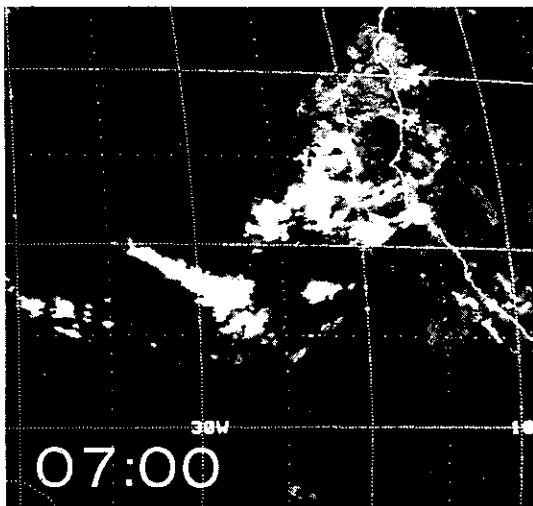


Figure 6. Hourly SMS/GOES imagery; 4×4 nmi resolution; September 6, 1974.

Table 2.
Classification Scheme Used to Evaluate Environmental Flow Field

Divergence		Curvature	
Flow Type	Code Number	Flow Type	Code Number
Strong convergence	1	Strong cyclonic	1
Slight convergence	2	Slight cyclonic	2
Neutral	3	Neutral	3
Slight divergence	4	Slight Anticyclonic	4
Strong divergence	5	Strong Anticyclonic	5

By 1600 GMT, the individual cloud systems had grown and merged into a well-defined cloud cluster centered near 27°W and 10°N. The cloudiness surrounding the cluster had become notably suppressed. Around 1800 another strong isolated convective system developed northwest of the main cluster near 34°W, 13°N. At 2000 GMT the cluster had a diameter of approximately 6° latitude. This disturbance continued to move westward, intensified slowly, and ultimately became tropical storm Alma.

4.2 August 18, 1974

The cloud systems that developed on this day are examples of the more typical life cycle of meso- β convective systems. Table 4 lists the times and locations of six different systems that developed between 0600 and 2300 GMT. Figure 5 presents the hourly satellite photographs for this period.

After a growth period of 3–5 hours, the systems began to dissipate, with a complete life cycle of 5–10 hours. On this day, the systems developed in a region of general low- and mid-level cloudiness associated with the Inter-Tropical Convergence Zone.

4.3 September 6, 1974

Figure 6 presents the hourly infrared images for 0700–1200 GMT Sept. 6, 1974. The feature of particular interest in this series is the very rapid mesoscale cloud development near 21°W, 14.5°N. This development occurred within an area of general high cloudiness so it was not included in the data set treated earlier. Note that as the thick cirrus deck expanded outward, a relatively clear region developed around the system. Evidently, compensating subsidence around the cloud system produced this clearing.

Figure 6 represents a very obvious example of mesoscale development within a larger scale disturbance. Although this particular study focused on the isolated meso- β -scale cloud systems, similar systems must also exist within many of the larger cloud clusters. Monitoring their development and decay using only satellite imagery is more difficult, however, because of the large amounts of cirrus cloud associated with the cluster.

Table 3
Environmental Flow Field Statistics

Level	Number of Observations	Average	Number of Observations	Average
Surface	65	2.4	68	2.8
850mb	57	3.1	58	2.9
700mb	58	2.9	58	3.1
500mb	45	3.3	47	3.2

5. Summary

Examination of SMS/GOES infrared imagery reveals the frequent occurrence of isolated meso- β -scale convective cloud systems in the tropical Eastern Atlantic. During July and August, the greatest frequency of storms is along 10°N. The data suggest a strong diurnal variation in the time of development, with the maximum occurring near midnight local time. There is an apparent tendency toward development in regions of low-level convergence and mid-tropospheric divergence. With the completion of the quality control of GATE rawinsonde and aircraft data, more exhaustive studies of the environmental settings during the growth of these systems should be undertaken.

Table 4.
Meso- β Convective Cloud Systems That Formed During the Period Shown in Figure 5

Time (GMT)	Location
0600	32.5°W-8°N
1200	25°W-10°N
1300	33°W-8.5°N
1500	27°W-11°N
2000	30°W-8°N
2000	36°W-7°N

6. Acknowledgments

Dr. Helmut K. Weickmann's interest in the strong convective systems in the GATE region initiated this research effort. The author acknowledges the helpful discussions with Dr. Weickmann and the assistance of Mr. Charles Bullard in performing the various computations. Data were furnished by the National Climatic Center, Asheville, N.C., and its Satellite Data Service Branch in Washington, D.C.

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